PCT WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification [5] : H02M 3/335, H02H 7/122	A1	(11) International Publication Number: **WO 94/22207** (43) International Publication Date: 29 September 1994 (29.09.94)

(21) International Application Number: PCT/FI94/00090

(22) International Filing Date: 11 March 1994 (11.03.94)

(30) Priority Data:
931137 15 March 1993 (15.03.93) FI

(71) Applicant (*for all designated States except US*): NOKIA TELECOMMUNICATIONS OY [FI/FI]; Mäkkylän puistotie 1, FIN-02600 Espoo (FI).

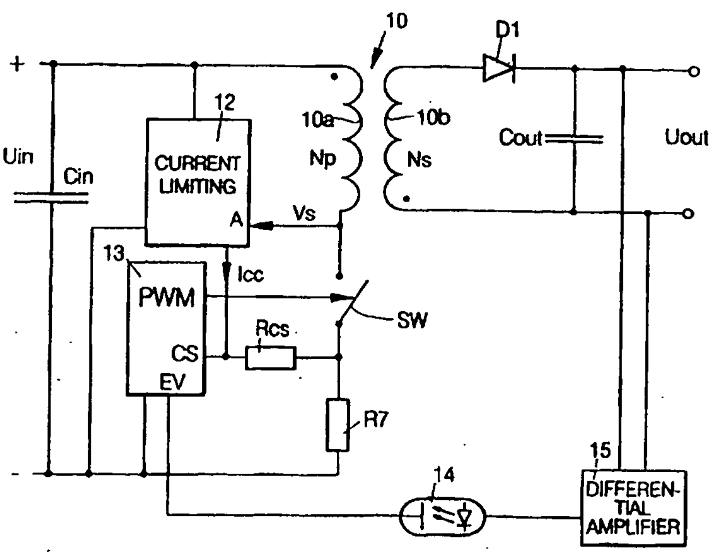
(72) Inventor; and
(75) Inventor/Applicant (*for US only*): BAARMAN, Gösta [FI/FI]; FIN-02570 Siunto kk. (FI).

(74) Agent: OY KOLSTER AB; Stora Robertsgatan 23, P.O. Box 148, FIN-00121 Helsinki (FI).

(81) Designated States: AT, AU, BB, BG, BR, BY, CA, CH, CN, CZ, DE, DK, ES, FI, GB, GE, HU, JP, KP, KR, KZ, LK, LU, LV, MG, MN, MW, NL, NO, NZ, PL, PT, RO, RU, SD, SE, SI, SK, TT, UA, US, UZ, VN, European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG).

Published
With international search report.

(54) Title: A METHOD FOR LIMITING THE OUTPUT CURRENT OF A SWITCHED-MODE POWER SUPPLY OF FLYBACK TYPE IN OVERLOAD SITUATIONS, AND A SWITCHED-MODE POWER SUPPLY OF FLYBACK TYPE



(57) Abstract

The invention relates to a method for limiting the output current (Iout) of a switched-mode power supply of flyback type in overload situations and to a switched-mode power supply of flyback type. In accordance with the method, the output current (Iout) is limited by means of pulse width modulation (PWM) by adjusting, by means of a control circuit (13) known per se, the ratio of the duration of the ON and OFF phases of the switch (SW) of the primary circuit. In order for the output current not to increase inordinately in overload situations, the voltage (Vs) which is present on the primary side of the transformer (10) and which is dependent on the output voltage (Uout) of the power supply is utilized to control a current generator (21), an output current (Icc) of which is used to form a control signal for the control circuit (13).

A method for limiting the output current of a switched-mode power supply of flyback type in overload situations, and a switched-mode power supply of flyback type

The present invention relates to a method in accordance with the preamble of the appended claim 1 for limiting the output current of a switched-mode power supply of flyback type in overload situations. The invention also relates to a switched-mode power supply of flyback type in accordance with the preamble of the appended claim 5.

Switched-mode power supplies have a constantly increasing part in the designing of power supplies. This is due to their several advantages, which include for example good efficiency, broad input voltage range and the possibility of achieving compact and light power supplies. Today in switched-mode power supplies, flyback topology is employed to an ever increasing extent (by topology is meant the circuit configuration determining how the power is transferred in the power supply). The greatest advantage offered by the flyback-type power supply is its simple and inexpensive structure which is suitable for use also in multiple-output power supplies. A flyback-type power supply is, however, attended by a certain disadvantage presenting problems particularly if the power supply has multiple outputs. This drawback is the output current that will increase excessively in short-circuit conditions or corresponding overload situations. When the load of a flyback power supply increases so that the control based on sensing of primary current, which is generally used in these power supplies, starts cutting the width of the switch-controlling pulse, the power supply will shift to nearly constant state. When the load is in-

creased and the output voltage decreases, the output current increases. The short-circuit currents are often inordinately high, particularly when the power reserved for the other outputs is transferred to the overloaded output. Separate current-measuring circuits intended for solving the problem will be inordinately costly and require special arrangements, since the control circuit is today usually located in the primary for reasons of economy.

U.S. Patent 4 908 755 discloses one method for limiting the output current of a flyback power supply. The control is effected by controlling the primary current peak value as a function of the input and output voltages. Also in this case the control is realized by means of a rather complicated circuit in which the parameters must be dimensioned so as to be able to simulate the formal interdependence between the input and output voltages and the peak value of the primary current in the flyback power supply.

It is an object of the present invention to eliminate the above drawbacks by means of a solution ensuring as cost-effective practical realization as possible. This is achieved with the method and power supply of the invention, the method being characterized by that which is set forth in the characterizing portion of the appended claim 1 and the power supply being characterized by that which is set forth in the characterizing portion of the appended claim 5.

The idea of the invention is to utilize the secondary voltage reflected through the transformer back to the primary side by forming of this voltage a control signal by means of which the switch-controlling circuit is controlled.

Because of the solution according to the invention, the cooling and foil of rectifiers need not be

over-dimensioned and, furthermore, in the designing of the secondary windings of the transformer, there is no need to safeguard against excessive currents in each winding. Further, possible damage on the load side in the case of a short circuit will be smaller.

In the following the invention and its preferred embodiments will be set forth in greater detail with reference to the examples according to the accompanying drawings, in which

Figure 1 shows a flyback power supply according to the invention,

Figure 2 is a block diagram of the current limiting circuit shown in Figure 1,

Figure 3 shows the interdependence of the control current supplied by the current limiting circuit of Figure 2 on the output voltage of the power supply,

Figure 4 shows a more detailed embodiment of the power supply shown in Figure 1, and

Figure 5 shows the behaviour of the output current and output voltage in a prior art power supply and in the power supply shown in Figure 4.

Figure 1 shows a flyback power supply of the invention, converting a rectified voltage Ui applied to the terminals of an input capacitor Ci to another direct voltage Uout which is present in the terminals of the output capacitor Cout. The power supply comprises in a manner known per se a transformer 10 through which the power is transferred from the primary to the secondary, a switch SW in the primary circuit chopping the primary current passing through the primary winding 10a, and a control circuit 13 controlling the switch; said circuit controls the output voltage Uout by regulating the duty cycle of the switch. The control is effected by means of pulse width modulation (PWM), in other words by adjusting the ratio of the duration of

the ON and OFF phases of the switch. In the secondary circuit, a rectifier diode D1 and an output capacitor Cout are connected in series in parallel with the secondary winding 10b.

The flyback power supply operates as follows. When the switch SW is closed (ON), a positive voltage is formed at the point ends of the transformer. In that case, an inverse voltage exists across the rectifier diode D1 of the output, and thus the diode is non-conductive. As a result, the secondary current is zero during the ON state of the switch. However, on the primary side the current passing through the switch increases linearly during the ON state. The transformer stores energy in its magnetic flux (air gap) during this phase, and thus the transformer is actually an inductance provided with a secondary winding. When the switch is directed to a non-conductive state (open, i.e. OFF), the energy stored in the magnetic flux of the transformer reverses the voltage of the winding (flyback phenomenon), in which situation the rectifier diode D1 of the secondary side starts conducting and a current starts passing through the secondary winding of the transformer. Unlike the primary current, the secondary current diminishes linearly during the OFF state. At the same time, the secondary current maintains the requisite output voltage across the output capacitor Cout.

If the load on the output increases, only the duration of the ON state of the switch need to be extended, as a result of which there is enough time for the primary current to increase, and thus during the OFF state the secondary current is respectively higher. The flyback power supply may operate either in the continuous state (there is no time for the secondary energy to become fully discharged after the flyback

state) or in the discontinuous state in which the energy is discharged fully at the end of each cycle. Also such flyback power supplies exist that operate in the continuous and discontinuous state, depending on the load. The power supply according to the present invention may be of any type described above.

The number of turns in the primary winding of the transformer is indicated by the reference Np and the number of turns in the secondary winding respectively by the reference Ns in the drawing. The switch SW is represented in the figure only as an ideal element illustrating its function; in practice the switch is typically realized with a MOSFET or a bipolar transistor. The control circuit 13 controlling the width of the switching pulse may operate either in the voltage mode based on the output voltage or in the current mode based on the primary current and the output voltage. The majority (about 80%) of the present-day switched-mode power supplies of flyback type utilize current mode circuits (with current mode control a better phase margin for the control is achieved than with voltage mode control). For this reason, the control circuit shown in the embodiment of Figure 1 is a control circuit 13 operating in the current mode and performing the control in response to the voltage information received from the differential amplifier 15 and the current information obtained from the switch. The voltage information is formed by comparing the output voltage to a reference voltage in the differential amplifier and by applying the difference signal to the difference voltage input EV of the control circuit through an opto-isolator 14, for instance. The current information is obtained from the switch SW through a resistor Rcs to the current measuring input CS of the control circuit. The information is obtained as a voltage

across the current measuring resistor R7 (having a small value compared to that of the resistor Rcs). The control circuit 13 may be of the type UC 3843 (or some other circuit of the same family), manufacturer Unitrode Corporation, U.S.A. Also other manufacturers have corresponding circuits.

The solution according to the invention utilizes the secondary voltage reflected back on the primary side. As is known, in a flyback power supply the voltage Vs across the switch in the OFF state is:

$$Vs = Uin + \frac{Np}{Ns}(U_{D1} + Uout) \qquad (1)$$

U_{D1} is the voltage across the rectifier diode D1 of the secondary. Since this voltage is small compared with the output voltage Uout, it need not necessarily be taken into account. In accordance with the invention, a separate current limiting circuit 12 is incorporated on the primary side, and the voltage across the switch is applied to the input A of said circuit. The output signal (output current) Icc of the current limiting circuit 12 is in turn connected to the current measuring output CS of the control circuit, wherein a control voltage is formed of the current Icc at resistor Rcs for the control circuit 13. The control circuit has a high input impedance, and thus no current passes therein.

The output signal Icc of the current limiting circuit is active only in overload situations, in which case it limits the output current Iout of the power supply, as will be set forth hereinafter.

Figure 2 shows the two main blocks of the current limiting circuit 12 of the invention, i.e. a peak value rectifier circuit 22 and a controllable current gener-

ator 21 controlled by said peak value rectifier circuit. The rectifier circuit 22 obtains in its input the voltage Vs referred to above. The current generator in turn is bound to the plus terminal for input voltage Ui and forms in its output a control current Icc that is inversely proportional to the output voltage Uout of the power supply. (Since the current generator is bound to the plus terminal for the input voltage Ui, a voltage Ug corresponding to the latter part of formula (1), being independent of the input voltage Ui, acts across it.)

Figure 3 shows the control current Icc emitted by the current limiting circuit 12 as a function of the output voltage Uout. When the output current has decreased from its nominal value Uout1 to a predetermined value k1*Uout1, the current generator 21 starts operating. If the nominal value Uout1 of the output voltage of the power supply is for example 5 V, the starting point could correspond for instance to 80% of the nominal voltage (k1 = 0.8). Thus the operation of the current generator starts when the output voltage has decreased to 4 V. Furthermore, the current generator is so dimensioned that its maximum current (corresponding to a total short circuit, Uout = 0 V) is not capable of fully closing the control circuit 13. The control circuit 13 has a threshold value closing the control fully, in which situation no power is obtained from the power supply. The present description employs, by way of example, a typical control circuit threshold value 1 V, corresponding to a current Ith = 1 mA when the value of resistance Rcs is 1 kΩ (the value of resistance R7 is very small, e.g. 1Ω, and thus it has no effect). The maximum value of the control current Icc is thus a predetermined portion, e.g. about 75% (k2 = 0.75), of said current threshold value Ith which fully

closes the control circuit 13.

Figure 4 shows a more detailed embodiment of the power supply shown in Figures 1 and 2. Figure 4 shows, for simplicity, only the configuration of the primary circuit, since the secondary circuit in this case corresponds to the configuration shown in Figure 1. Further, the feedback loop formed by the differential amplifier and the opto-isolator has been left non-insulated. A Zener diode Z1 and a resistor R3 are connected in series between the input terminals (the input capacitor Cin is not shown in Figure 4). A resistor R2 leads from their common node to the base of p-n-p transistor Tr1, to point P1. The emitter of the transistor is connected through resistor Rg to the plus terminal of the input voltage Ui. The collector of the transistor is connected to the common node of the current measuring input CS of the control point 13 and resistor Rcs. The base of the transistor is also applied through a resistor R1 to point P of rectifier circuit 22, said point being connected to the minus terminal of the input voltage through capacitor C1. The common terminal of the primary winding and switch SW has also been connected to point P through the series connection of resistor R5 and rectifier diode D2. Resistor R5, diode D2 and capacitor C1 form a peak value rectifier circuit 22, and point P thus constitutes a feed point wherefrom the voltage according to formula (1) above is supplied to current generator 21 formed by Zener diode Z1, resistors R1-R4 and Rg and transistor Tr1. As can be seen from formula (1), this voltage supplied to point P decreases when the output voltage Uout decreases (short circuit).

In its other parts, the primary circuit corresponds to the configuration shown in Figure 1, that is, the current measuring input CS of the control circuit

13 is coupled through resistor Rcs to the other terminal of the switch, said terminal being connected through resistor R7 to the minus terminal of the input voltage Ui.

In order for the current generator 21 to operate in the manner described above, the resistance values of the circuit must be correctly dimensioned. In the following, the same exemplary values are used as in connection with Figure 3, and it is further assumed that the number of turns in the primary winding of the transformer is 13, the number of turns in the secondary winding is 3, and resistor R2 biases the Zener diode Z1 in such a way that the voltage across the Zener diode is 6.2 V. In a balance situation (i.e. in a situation where the output voltage Uout has decreased to the threshold (4 V) at which the current generator starts operating), transistor Tr1 is just becoming conductive, in which situation its base-emitter voltage is about 0 V (0-0.2 V). The current through resistor Rg is still zero, and thus the voltage across resistor R2 must correspond to the voltage across the Zener diode. If it is assumed that resistance R2 has a value of for instance 56 kΩ, the current I2 through resistor R2 is about 110 μA. In a balance situation, the voltage at the base of transistor Tr1 (at point P1) is ≈Uin and the base current of the transistor is zero, and thus the current I2 can be obtained only through resistor R1. Since the voltage across resistor R1 is ≈17.3 V (13/3 * 4 V), the value obtained for resistance R1 is R1≈150 kΩ.

When the output voltage Uout is higher than 4 V, the current passing through resistor R1 is respectively higher, and the base-emitter voltage keeps the transistor in the closed state. When the output voltage decreases to 4 V, the control current Icc starts flowing, and the more the output current decreases, the

smaller is respectively the cancelling effect obtained through resistor R1, and thus the control current Icc is respectively higher.

In the other extreme situation, there is a total short circuit in the output of the power supply (Uout = 0 V), and thus the voltage of point P is VP≈Uin (assuming that diode D1 is ideal, i.e. the voltage across it is zero). In that situation, the value of resistance Rg is Rg≈5,7 kΩ (assuming that the gain of the transistor is for instance 30) when the desired maximum value of the current Icc is about 750 μA (the voltage across resistor Rg is 6.2 V minus the base-emitter voltage of the transistor, which is about 0.5 V, and the voltage across resistor R2, which is about 1.4 V).

The value of resistance R3 shall be so dimensioned that the current passing through resistor R2 cannot interfere with the bias of the Zener diode Z1.

By changing the ratio of resistances R1 and R2, the limiter threshold (Uout ≈ 4 V) of the current generator can be varied. On the other hand, by changing the value of resistance Rg, various limiting curves can be produced. These curves are described in the following.

Figure 5 shows the output current Iout of the power supply shown in Figure 4 as a function of the output voltage Uout. The balance point is indicated by reference B. The normal operational range is one in which the output voltage Uout is maintained at its nominal value Uout1 (for example 5 V). The angle point L corresponds to the threshold of the control circuit 13 at which the sensing of primary current of the control circuit starts cutting the pulse width and the power supply shifts to nearly constant state in which the interdependence of the output voltage and output

current is illustrated by curve D. However, in accordance with the invention a balance point B of the kind described above is provided, and starting from that point the output current is further limited by means of the control current Icc supplied by current generator 21. When the output voltage Uout decreases to the balance point, the output current is thus limited more effectively than heretofore, the interdependence of the output voltage and output current being represented for example by one of the straight lines F1-F5. The direction that said limiting curve will take depends on the value of the resistance Rg. The useful region has been indicated by an arrow H in the figure. If the value of resistance Rg increases to be in excess of the value corresponding to the straight line F5, there is a shift from region H towards curve D, in which situation the solution of the invention is of little utility. On the other hand, if the value of resistance Rg decreases below the value corresponding to the straight line F1, the power supply remains closed. As stated previously, by changing the ratio of resistances R1 and R2 the location of the balance point B on curve D can be altered.

Even though the invention has been set forth in the above with reference to embodiments according to the accompanying drawings, it is obvious that the invention is not to be so limited, but it may be varied within the scope of the inventive idea disclosed above and in the appended claims. For example, in practice the power supply may have several outputs, even though the exemplary embodiments set forth above have only one output. Also the detailed realization of the current generator may vary in many ways. The structure described above, however, affords incorporation of the additional features offered by the invention in

switched-mode power supplies of flyback type as economically as possible. It is in principle also possible to utilize the solution according to the invention in connection with a control circuit operating in the voltage mode, even though the invention has been described above only in connection with a circuit operating in the current mode. However, if it is wished to employ a circuit operating in the voltage mode, a control signal suitable for the voltage mode circuit (e.g. UC 3524, manufacturer Unitrode Corporation, U.S.A.) must be formed of the control current Icc. In that case, the solution will be more complex than that disclosed above, and at the same time the advantages of a control circuit operating in the current mode over a control circuit operating in the voltage mode are lost.

Claims:

1. A method for limiting the output current (Iout) of a switched-mode power supply of flyback type in overload situations, according to which method the output current (Iout) is limited by means of pulse width modulation (PWM) by adjusting, by means of a control circuit (13) known per se, the ratio of the duration of the ON and OFF phases of the switch (SW) of the primary circuit, characterized in that the voltage (Vs) which is present on the primary side of a transformer (10) and which is dependent on the output voltage (Uout) of the power supply is utilized to control a current generator (21), an output current (Icc) of which is used to form a control signal for the control circuit (13).

2. A method as claimed in claim 1, characterized in that an output current (Icc) deviating from zero and inversely proportional to the output voltage (Uout) of the power supply is supplied from the current generator (21) when the output voltage has decreased to a predetermined fraction (k1) of its nominal value (Uout1).

3. A method as claimed in claim 1, characterized in that the maximum current supplied by the current generator (21) is maintained below the threshold current (Ith) fully closing the control circuit (13).

4. A method as claimed in claim 3 wherein the control circuit (13) operates in the current mode, characterized in that the output current (Icc) of the current generator (21) is supplied to the current measuring input of the control circuit (13), to which a signal proportional to the primary current of the transformer (10) is also provided in a manner known

per se.

5. A switched-mode power supply of flyback type, comprising a transformer (10) which is provided with a primary and a secondary winding (10a, 10b) and through which power is transferred from the primary to the secondary, a switch (SW) in the primary circuit whereby the primary current passing through the primary winding (10a) of the transformed is chopped, and a control circuit (13) controlling the switch, said circuit controlling the output voltage (Uout) of the power supply by means of pulse width modulation by adjusting the ratio of the duration of the ON and OFF phases of the switch (SW), characterized in that it comprises means (21, 22) for forming a discrete control signal (Icc) in response to the voltage (Vs) which is present on the primary side of the transformer and which is dependent on the output voltage (Uout) of the power supply, said means switching said control signal to the control circuit (13).

6. A power supply as claimed in claim 5 the control circuit (13) of which is a current mode circuit, characterized in that said means comprise a peak value rectifier circuit (22) to which said voltage (Vs) is connected, and a current generator (21) to which the output of the rectifier circuit is connected, the output of said current generator being connected to the current measuring input (CS) of said control circuit (13).

7. A power supply as claimed in claim 6, characterized in that the current generator (21) is connected to the plus terminal of the input voltage (Uin).

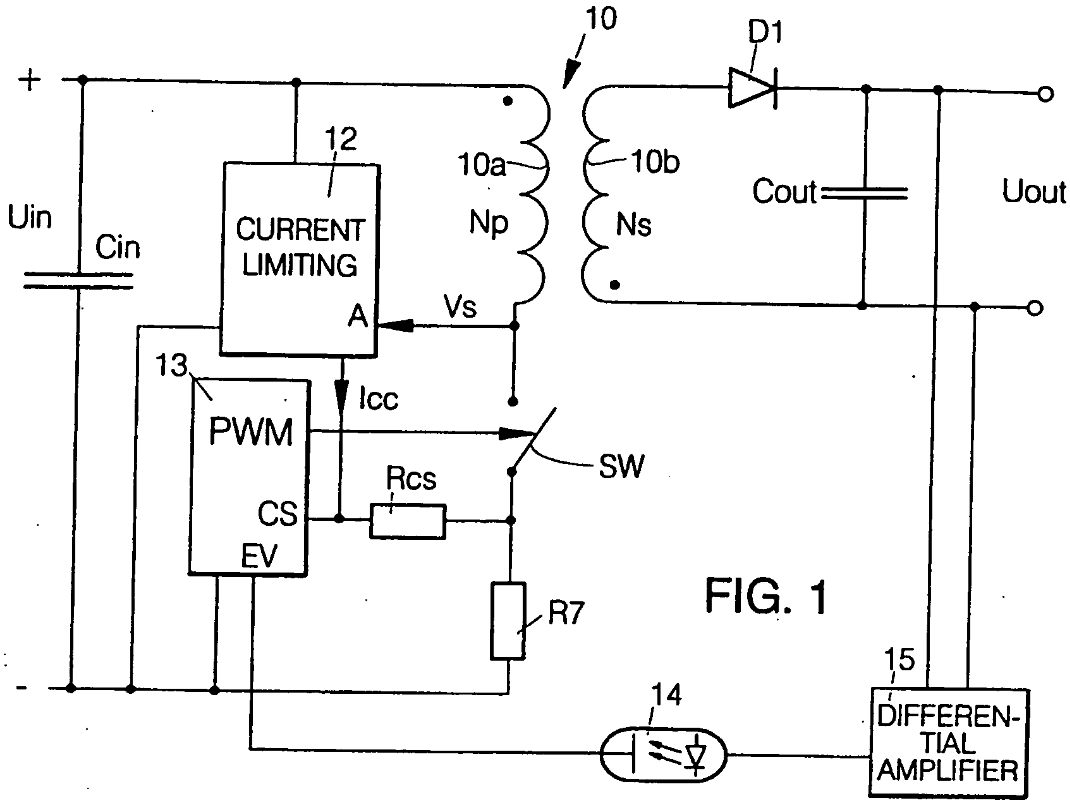


FIG. 1

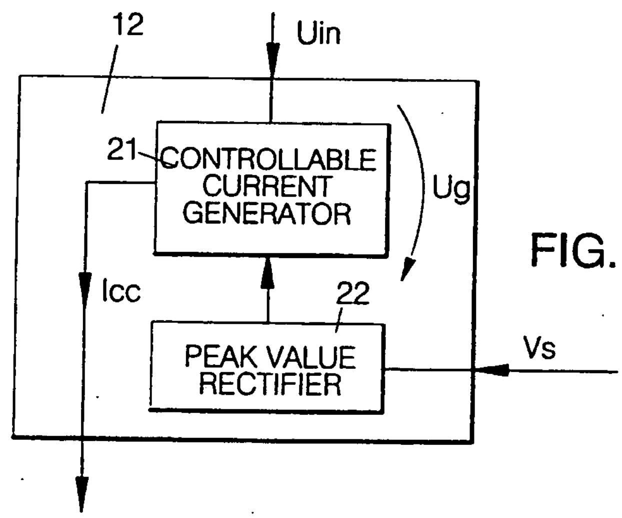


FIG. 2

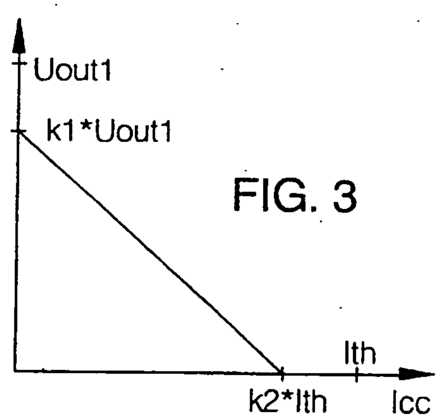


FIG. 3

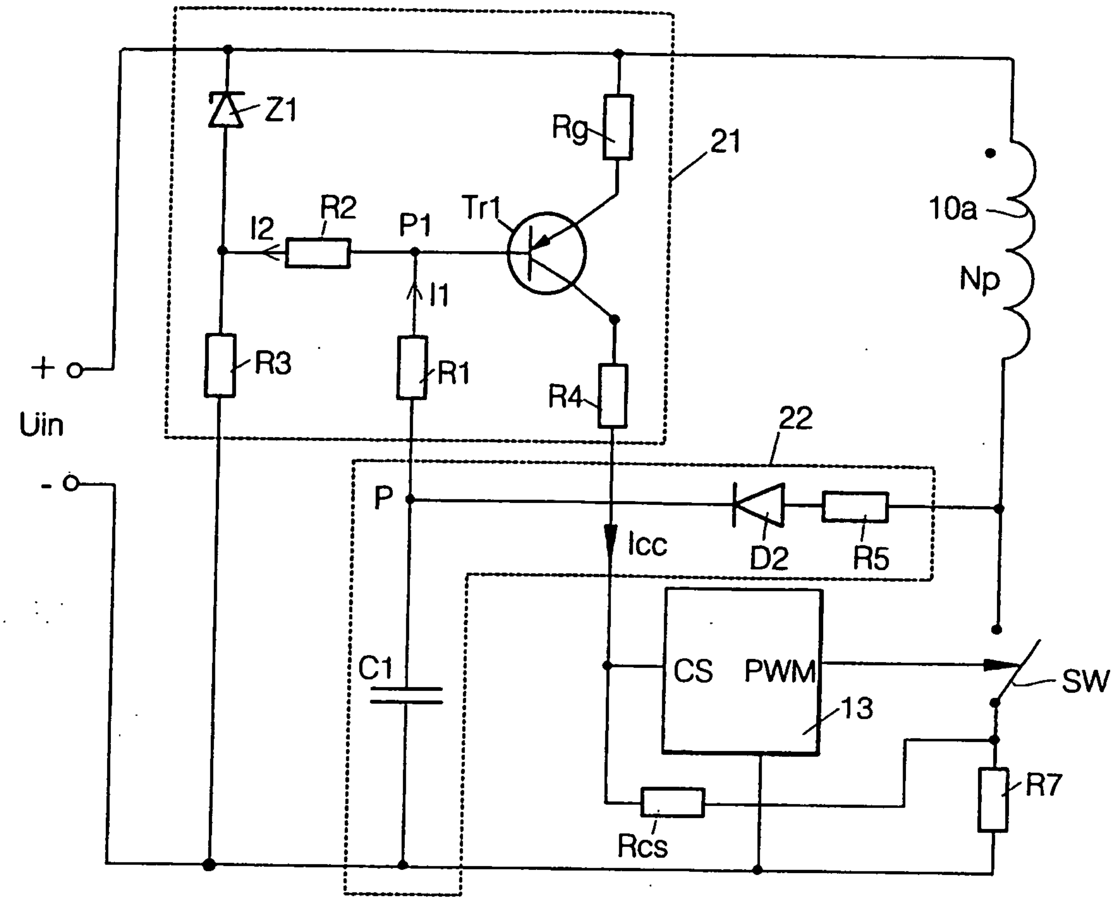

Z1
Rg
21
10a
I2
R2
P1
Tr1
Np
I1
+
R3
R1
R4
Uin
-
22
P
Icc
D2
R5
CS
PWM
SW
C1
13
R7
Rcs

FIG. 4

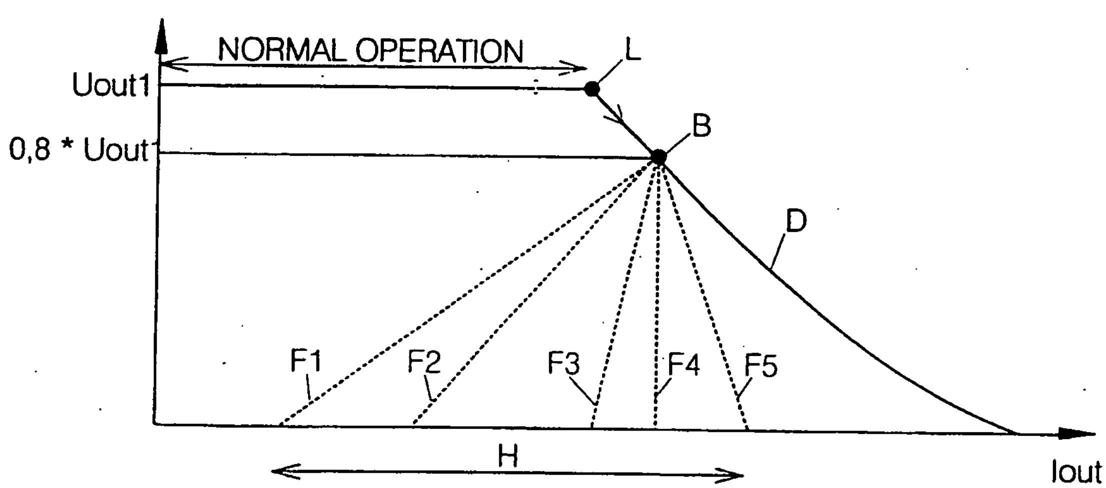

NORMAL OPERATION
L
Uout1
B
0,8 * Uout
D
F1
F2
F3
F4
F5
H
Iout

FIG. 5

INTERNATIONAL SEARCH REPORT

International application No.
PCT/FI 94/00090

A. CLASSIFICATION OF SUBJECT MATTER

IPC5: H02M 3/335, H02H 7/122
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC5: H02M, H02H

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US, A, 4908755 (MARTIN FELDTKELLER), 13 March 1990 (13.03.90), abstract --	1-7
A	US, A, 4425611 (FINIS C. EASTER), 10 January 1984 (10.01.84), column 2, line 27 - column 3, line 42 -- --------	1-7

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" erlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
23 June 1994	05 -07- 1994

Name and mailing address of the ISA/	Authorized officer
Swedish Patent Office Box 5055, S-102 42 STOCKHOLM Facsimile No. +46 8 666 02 86	Håkan Sandh Telephone No. +46 8 782 25 00

INTERNATIONAL SEARCH REPORT
Information on patent family members

28/05/94

International application No.
PCT/FI 94/00090

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US-A- 4908755	13/03/90	EP-A,B- 0335194	04/10/89
US-A- 4425611	10/01/84	NONE	